A Comprehensive Modeling Language for Clinical Processes

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Abstract: In this paper we present a comprehensive modeling language for clinical processes that integrates requirements from the medical, organizational and economical dimension into a single clinical process model. The design of this modeling language is heavily influenced by the experiences we made when documenting the processes at several clinics in Germany. Thus, we introduce the features of this modeling language by examples. We show that extensibility is one of the key features of this type of domain specific language and describe the principle idea of its implementation in the second part of the paper.

1 Introduction

The medical domain is one of the most challenging applications for IT technology [Ander97][DRKu00]. Among other IT technologies like pattern recognition and data management (e.g. Hospital Information Systems, HIS), process management is acknowledged as a powerful integration technology for medical applications. We studied and established medical processes in several German Clinics (University Clinics of Marburg [BJK+04], University Clinics of Erlangen-Nuernberg [JLM+05], and Fuerth Clinics). Especially in the Fuerth Clinics we investigated the question: What matters must be included into a medical process? The analysis of this question encountered three major impacts onto medical processes which directly determine the matters that have to be incorporated into a Clinical Process model: medical, organizational and economical. This result is substantiated by the observation that clinics nowadays find themselves between increasing cost pressure and the obligation to ensure best class medical services. As a consequence Clinical Processes must be made more transparent, economically assessed and optimally embedded into the organizational structures of the clinics. Subscribing to these three different impact categories makes it a challenging task to design a suitable model for Clinical Processes. From now on we change the viewpoint of the discussion slightly and talk about three dimensions that have to be reflected by a Clinical Process: the medical, the organizational and the economical dimension. In the following section we discuss the conceptual basis of these three dimensions.

There are two different kinds of sources backing up the medical dimension. On the one hand side, there are so called Medical Directives which are mandatory guidelines for patient treatments. They are typically defined by official bodies like government related organizations. When disobeying them, penalties have to be paid. On the other hand side, there are so called Medical Guidelines which define evidence based clinical paths [CRR+92]. Typically, domain specific bodies (e.g. "Bundesärztekammer" in Germany) publish them. Also there is a great discrepancy of interpretations in literature; we want to determine for this publication that processes which are set up after Medical Guidelines and Medical Directives are called Clinical Paths (Fig. 1). A Clinical Path encompasses all medical requirements. According to the above observation organizational and economical concerns still have to be incorporated into Clinical Paths. Typically, there is only one source for organizational requirements: the individual clinic itself. Often, a clinic defined mission statements or organizational guidelines which summarize them. For the economical dimension, there are typically two types of resources. Again, there is an official source with mandatory requirements. In this paper we just refer to Diagnosis Related Groups (DRG) [Fisc01], a system that classifies illnesses and injuries into groups. Patients are sorted into these groups depending on the diagnosis; patients within one category are clinically similar and are expected to use the same level of hospital resources. Payments from the health insurance to a hospital depend only on DRGs. Another type of economical impact is named "Optimization Criteria" in Fig. 1; it summarizes all internal criteria of a clinic which are set up to define the metrics for clinical services. We use the term Clinical Process to determine those processes which reflect all three dimensions, i.e. the medical, the organizational and the economical one.

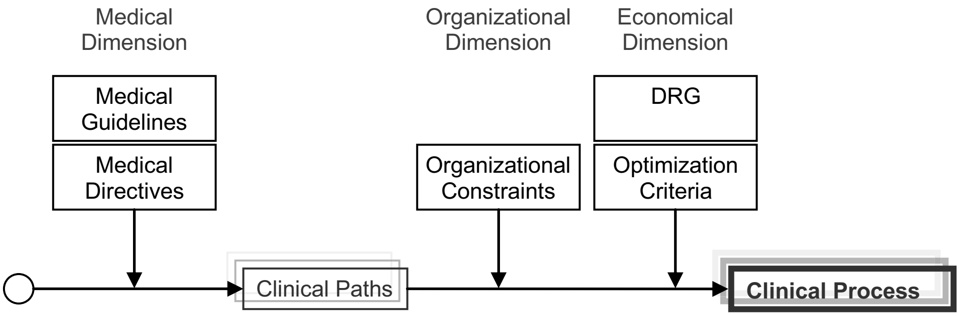

Fig. 1. Taxonomy of clinical/medical process categories

The Clinical Process model investigated in this paper takes into account all three dimensions. Although a process modeler finally wants to gain an integrated process model which comprises all impact dimensions together, it is often interesting to analyze the reasons why certain features are incorporated into a process model. So, it can be distinguished whether they are stemming from medical, organizational, and/or economical considerations. We will show in the following section several use cases which illustrate this issue and how it can be used to increase process readability.

From a technical point of view, the requirements compiled above lead to a process modeling language that must be extensible by dimension specific features. Why extensible? In principle, each clinical application can impose new requirements which cannot be foreseen. Thus, these requirements must be integrated ex post into a modeling language for clinical processes. These features might be represented by completely new modeling constructs or by new attributes of an already existing modeling construct. Furthermore they must be analyzable in an integrated way and per impact dimension separately.

In Section 2 we will list several examples that we encountered while modeling the Clinical Processes in the Fuerth Clinics. Section 3 provides an overview on the implementation of an extensible process modeling languages for Clinical Processes.

2 Reconstructing Clinical Processes

Our goal was to provide a tool which supports modeling and analysis of the medical, organizational and economical dimensions. Clinical Processes can be assigned to one or several of these dimensions. Hence, a single process step is not necessarily assigned to exclusively one dimension; for instance, the process “take-up to the hospital” has impact on both the organizational and the economical dimension. Each process step can be assigned to the medical, organizational or economical dimension by the use of specific tags. We will also introduce two new modeling constructs needed to reflect the specific demands of clinical applications. We introduce our domain specific modeling language and its features in the following use cases.

2.1 Medical Dimension

Processes which are directly linked to the treatment of patients belong to the medical dimension. In the following section we describe applications of our approach which help to provide best class medical services. As already mentioned in Section 1, this is one of the key challenges in the construction of processes in this area.

MED1: Medical decision support. At certain points of a Clinical Process a physician must decide how to continue the treatment of a patient. Such a decision is made mostly with respect to multiple criteria. Some of them will influence the decision in one direction while other criteria will have the contrary effect. The challenge in praxis is that it is normally not possible to define a hierarchy on the criteria. So each combination of criteria can lead to a different result. In the perspective oriented modeling approach this can be accomplished by using a series of simple binary deciders. Each of these deciders represents a fragment of the real medical decision. In Fig. 2 (left part) a medical decision using simple deciders is illustrated. Although this process model contains all information about the medical decision, such a model is complicated and hard to grasp. Also, the original intention of a composite, but single decision is completely lost. Moreover it is not possible for an information system to identify them as a single decision. Hence, if this decision support is modeled by a sequence of if-else decisions, the visualization of such a decision is going to be quite unpleasant. To overcome these disadvantages of the classical representation, we define a new construct: the *Medical Decider* (Fig. 2, right part). This composite construct encompasses all simple deciders and groups them in only one single symbol. Thus the concept of a composite decision can be easily grasped. Moreover, additional logic (e.g. a Clinical Algorithm) can be added to this construct. In Section 3.2 the implementation of the Medical Decider is discussed. The overall goals of the introduced construct Medical Decider is to support a complex decision and to make it transparent to participants of the process.

Fig. 2 describes the decision whether or not a hip replacement is indicated for a patient. Criteria defined by the AWMF [AWMF07] (Association of the Scientific Medical Societies in Germany) for this type of operation are applied in this process. It is obvious that the model lacking the Medical Decider is overloaded and it is not possible to reproduce the decision making in an easy and transparent way. In contrary the figure using the Medical Decider is well structured and the criteria used to make the decision (depicted in the grey box) are transparent.. Furthermore the possibilities of the Medical

Decider in connecting the criteria with an internal logic support the implementation of Clinical Algorithms (cf. Section 3.2).

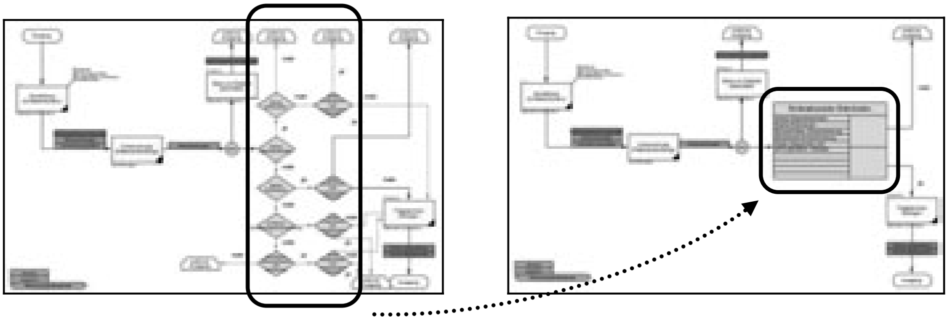

Fig. 2. Medical Decider

MED2: Checklist. In a clinical environment nurses and physicians find themselves in situation in which lots of small activities have to be performed. Normally the sequence in which these activities are executed is secondary. The goal of the modeling construct which is introduced here is to describe these kinds of situations. Usually, those activities have to be modeled as normal processes. An example is the preparation of a patient for a surgery as depicted in Fig. 3 (left part). During this preparation many short activities have to be performed, e.g. the patient has to be shaved partially and has to get medicaments. Although the order of these steps is completely free (this is typical for such situations), some kind of flow has to be modeled using a normal process modeling language. There are at least two problems connected with such a representation: first, it does not reproduce the fact that these activities strongly belong together to one critical execution phase. Second, the process model suggests a certain execution order which is not given.

Alternatively, Checklists – as a new modeling construct – describe activities of this kind and foster the complete execution of all tasks (Fig. 3, right figure). The main advantage of a Checklist is the following: Tasks in a Checklist do not need to be modeled as comprehensive processes which would drastically blow up process models. Applying the Checklist modeling construct leads to a compact and transparent visualization.

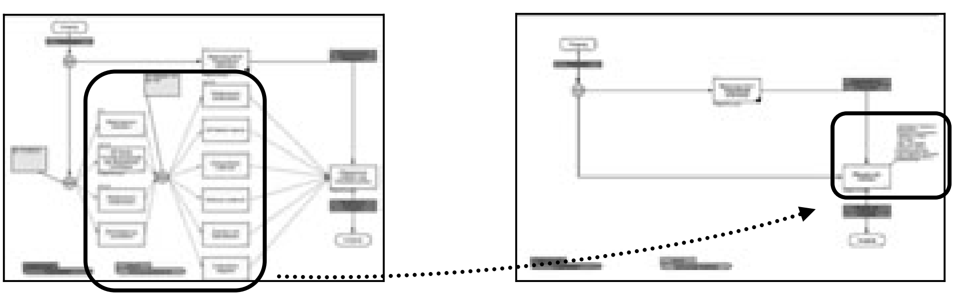

Fig. 3. Checklist

MED3: Highlighting steps in a path. The goal of this third extension of a process modeling language is to highlight processes and data which are necessary from the perspective of a medical treatment. The implementation of this requirement is rather straightforward. Tasks with an active tag in the medical dimension are marked with a red cross in the corresponding process description (cf. Fig. 4). This tagging can be used to distinguish quickly medical activities from organizational or economical ones in a compact visualization. Furthermore this feature directly supports the effort to make Clinical Processes more transparent, which is one of the key challenges in the modeling of clinical applications (cf. Section 1).

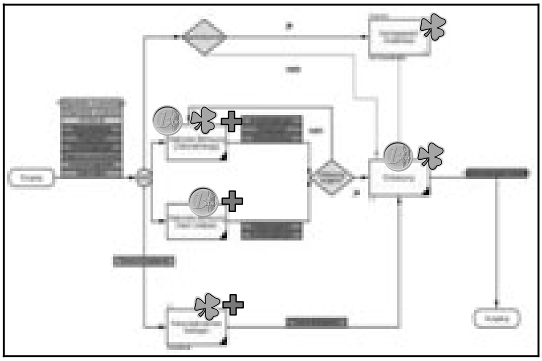

Fig. 4. Tagging of process steps

MED4: Attachment of medical guidelines, directives or hospital specific information. For each process step, knowledge sources (medical guidelines or directives, legal regulation, etc.) are provided. When a certain process step is executed, these knowledge sources can be used to get information of – for example – a special treatment technique. This feature supports younger employees in preparing difficult process steps by providing them with state of the art knowledge. Furthermore, experienced employees can be informed about new medical achievements or legal requirements in this way. In addition also hospital specific information such as the temporal unavailability of certain resources can be made accessible. Fig. 5 describes such a provision of medical background information. The process of finding the correct diagnosis is connected with information about diagnosis techniques and possible disease patterns. This feature is linked as an extension of the standard perspectives (Section 3.1) to process steps and is called knowledge perspective (Section 3.2).

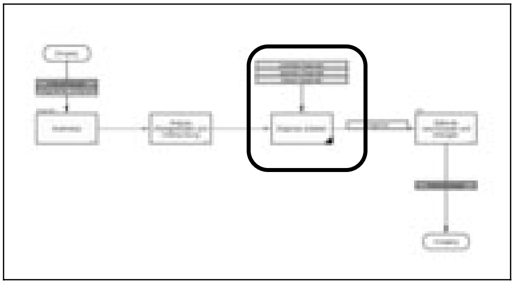

Fig. 5. Adding medical background information

2.2 Organizational Dimension

The organizational dimension is the link between the medical and the economical dimension. A change in the organization always impacts at least one of the other two dimensions.

ORG1: Creation of a schedule for each patient, room and service provider. The goal of this analysis is to provide a tool which visualizes the schedule for a patient during the stay in a hospital. During a normal day, at certain times patients are not available for examinations. Reasons for these regular non-availabilities are e.g. meals or the ward round. Between those fixed times, time corridors can be identified in which patients are available for diagnostic examination or physiotherapy. This perception can be extended from a patient based to a resource based perspective. Important resources in this context are examination rooms, technical equipment, the operation room and all service providers of a hospital. By gathering this information and creating a schedule it is possible to group actions in an effective way, e.g. if there are several X-ray examinations planned at the same day, it is possible to group them so that they can be executed together (cf. Fig. 7). To realize the above described analysis, information about the location of steps in a Clinical Process are needed (cf. "room" attribute, Section 3).

ORG2: Highlighting of steps in a path which are relevant for the organizational dimension. Analogous to MED3 special steps which strongly depend on the organizational structure of a specific clinic, e.g. the Fuerth Clinics are highlighted (cf. Fig. 4). A process is tagged as organizational in this picture with the symbol of the shamrock (which is the symbol of Fuerth). Here the goal is not to improve medical treatment, but to highlight process steps that highly depend on organizational constraints of a certain clinic. Consequently, this feature is addressed to decision makers and especially it is of most interest for quality management departments and points to steps that can be changed or optimized without affecting the medical effectiveness of the process.

2.3 Economical Dimension

Increasing cost pressure (Section 1) forces hospitals to focus on the costs of medical treatment. This is directly related to the introduction of the DRG system as all patient related costs of the hospital previously were refunded by health insurances. The following applications demonstrate extensions which offer effective tools to control costs along a Clinical Process and reflect the economic needs of the hospital as a market participant.

ECO1: Cost-Monitoring. Each process is linked to information about its average execution costs. As it is crucial for the controlling department to keep track of financial ratios, these average cost can be used as a basis for an actual cost comparison. Also cost drivers can be identified. This analysis can be used for the construction of a more effective organization of the hospital.

ECO2: Separating costs into costs for medical treatment and for administration. This separation is realized by the contents of the medical, organizational and economical tags (cf. MED3, ORG2, ECO5 and ECO1). It is then easy to reflect how much money is spent for administration and for the treatment of the patients. The ratio between these figures provides an index for the effectiveness of the administration. This feature provides useful information for the controlling department by assigning the expenses to the corresponding dimensions.

Either the requirement ECO1 or ECO2 needs specific process attributes that reflect cost categories for process execution.

ECO3: Indication of processes relevant for the DRG classification. Each Clinical Process is associated with a special classification with respect to the DRG system. This classification is the key factor for a hospital to be reimbursed by health insurances. Beside the main diagnosis, side diagnoses have a tremendous impact on this payout. Moreover the process of identifying these side diagnoses is a complex and time-consuming task. The association of processes with relevant information for side diagnoses simplifies the classification and identification of side diagnoses. In addition some side diagnoses remain undetected because of the opacity of the actual systems. So this analysis tool prevents DRG classification of refundable costs to be forgotten. Consequently, process descriptions must be extended by an attribute that refers to the DRG classification.

ECO4: Marking services as optional. By using tags, each process can be marked as a standard operation or as an optional service (specific attribute). As there are several types of contracts for optional services, it is possible to assign process steps to contracts by using a tag for each contract type. This helps connecting each process step with an internal logic. As many of those optional contracts determine the person who has to execute a specific process, this internal logic can be used to assign the appropriate person. For example, if a patient chose chief physician treatment, every process step in which a physician is in charge is associated with a person who has the position of a chief physician.

ECO5: Highlighting of steps in a path which are relevant for the economical dimension. Comparable with the previous scenarios **MED3** and **ORG2** processes are highlighted which are here assigned to the economical dimension (cf. Fig. 4). The tag for the economical dimension is symbolized by a coin.

2.4 Synthesis

As already mentioned in the beginning of this section, a process may be associated to more than one dimension. These processes are key elements of process optimization and hard to handle. The following demonstrates a feature which deals with all three dimensions. The deliberate use of this feature enables enormous benefits.

SYN1: Detection of processes which cause patients to have to stay longer in the hospital. The goal is to analyze those processes and decisions which lead to a prolonged stay in the hospital. Since loops in a process model are one of the main reasons for delays, one of the tasks of this analysis is to identify loops. They have to be assessed whether they are unavoidable or are a cause for an extended stay in the hospital. An extended, avoidable stay means additional costs which cannot be reimbursed because of the structure of the DRG system. But also the patient benefits from such an analysis, since finally he will be happy to have a shorter stay in the hospital.

We introduced the above presented features in several clinical applications. The feed-back to these extended process models has always been positive, since they contribute decisively to the readability of process models. As we already mentioned, readability of process models is one of the key prerequisites of the acceptance of process management in clinics.

3 Implementation of an Extensible Process Modeling Language

In Section 2 some essential modeling features for medical processes are introduced. According to the classification from Section 1 they are associated with the medical, organizational and economical dimension of a Clinical Process. In this section we describe how a process modeling language must be constructed in order to provide extensible domain specific features as identified in Section 2. However, it is not the purpose of this paper to discuss implementation details; we aim more at conveying the main conception of the implementation of the extended features. Implementation details are subject to the cited references.

3.1 Perspective Oriented Process Modeling

We pursue an approach which is called Perspective Oriented Process Modeling (POPM) [JaBu96]. POPM is a special form of aspect oriented modeling. Aspect oriented modeling aims at introducing crosscutting concerns encapsulated in aspects into software artifacts [KLM+97]. In principle, this is a matured form of software modularization that supports rapid software development which is heavily based on software reuse.

POPM fosters similar goals, however it is restricted to process modeling (and execution) and therefore very efficient in this field. The key feature of the POPM approach is to modularize process modeling constructs into independent perspectives. Each perspective represents a specific facet of a process modeling construct. There are many publications about the definition and identification of perspectives, e.g. [Jabl94] [JaBu96]; therefore, we merely summarize the main perspectives of a process modeling construct here.

- The functional perspective describes the purpose and goal of a process; it embodies the backbone of a process modeling construct.
- The organizational perspective describes the agents (e.g. people) responsible and eligible for a process.
- The operational perspective describes the tools/software/systems necessary to execute a process.
- The data perspective describes the necessary input and output data for a process element. It also describes data related dependencies between processes.
- The behavioral perspective describes temporal and modal dependencies between processes. Together with data related dependencies this perspective determines the control flow between process elements, i.e. execution order.

One of the major characteristics of the POPM approach is that the above list of perspectives is neither obligatory nor sufficient. If one or more of the described perspectives are not necessary they can just be removed. However, the functional perspective should always be present, since it bears both the structural basis and the semantic description of a modeling construct. Also, if one or more new perspectives are necessary, they can be added. A process modeling construct is composed of one or more perspectives. For example, a process step typically consists of the functional perspective (defines name and purpose), the organizational perspective (defines agents responsible to perform it) and the operational perspective (which defines the tools needed to execute it). A flow control construct merely is composed of the behavioral perspective.

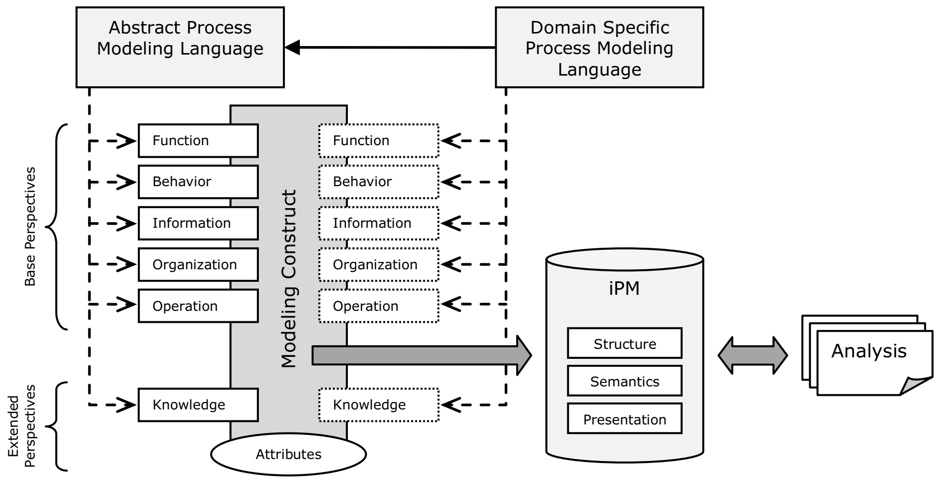

Fig. 6. Toolkit Concept

Fig. 6 depicts the principle structure of POPM. The perspectives are shown in the middle of the figure. Each perspective is not directly implemented but by the provision of a meta-model [JLM+05]. Since perspectives are reduced to specific areas of concern, this is possible and suitable. The only fixed element of the POPM implementation is the so called Process Skeleton. This element is necessary to interpret a process modeling language, i.e. the modeling constructs that are available. Such an interpretation is performed according to the following algorithm: Starting at the Process Skeleton, the currently relevant perspectives are determined. Each identified perspective is then interpreted according to the current implementation of its meta-model. The composition of perspectives for process modeling constructs defines the structure of a process. Its semantic is defined by constraints on their interpretation (refer to [JLM+05] for further details). Also, each process modeling construct is associated with some presentation for depicting it by a modeling tool.

We are using the process modeling tool iPM (integratedProcessManager, [ProD06]) to model Clinical Processes. One of the major advantages of iPM is its extensibility. This is due to the fact that iPM implements POPM as described above. Also, iPM stores all process descriptions in a relational database and offers an open interface to this data store. It means that all stored data, i.e. process models, can be inquired arbitrarily. This feature facilitates the definition of arbitrary analysis tools as required by some of the scenarios in Section 2. In the following section we reconstruct the major modeling constructs and analysis functions used in the process models depicted in Section 2.

3.2 Extensions for Clinical Processes

Extending a process modeling language can be done in several ways. iPM offers the possibility to add new attributes, modeling constructs or perspectives. All these extensions aim at different targets and can be used to add different characteristics. In this section we will discuss all three possibilities and explain what extension mechanism was used to implement the modeling situations presented in Section 2.

The most basic option to extend the modeling language is to add a new attribute to a modeling construct. This approach can be used only for simple extensions (cf. MED3, ECO1 to ECO4) to the modeling language. The prerequisite of this approach is that these extensions can be integrated into existing constructs and do not need a separate representation. In scenario MED3 an additional (extended) attribute is used to tag a process step as belonging to the medical dimension. Typically, extended attributes refer to a predefined domain of values. For example, the extended attribute in scenario MED3 is also used to determine processes which belong to the organizational or economical dimension. So this attribute can take one or more of the values "Medical", "Organizational" or "Economical". "Room" as mentioned in ORG1 is another example of an extended attribute.

For MED1 (Decision Support) and MED2 (Checklist) attributes are not sufficient to model the posted requirements. Although the situation can be solved by using existing basic constructs (Fig. 2, Fig. 3), the resulting model will be hard – if not impossible – to read. Our solution is to introduce new modeling constructs, which induce compact representations. New constructs can be divided into two groups: constructs that combine multiple existing constructs into a new one (this is a kind of macro) and constructs which aside from the new representation also introducing new semantics.

For MED1 (Fig. 2) a new construct called *Medical Decider* was introduced to model a medical decision compactly. A Medical Decider contains a list of inquires that are relevant for a certain medical decision. Medical Deciders also comprise additional components. It can reference to decision tables as well as to advanced Clinical Algorithms (e.g. in Arden Syntax [Arde07]). During process execution, a reasoning system can evaluate this data and create a recommendation for the physician.

Scenario MED2 (Fig. 3) describes another situation, where existing modeling elements are not sufficient to model a Clinical Process adequately: Too many small process steps blow up the model and conceal almost the central steps of the path. By introducing the new construct *Checklist*, it is possible to model situations with lots of small steps that can be executed in arbitrary order compactly.

As Section 2 demonstrates, the usual five perspectives of a process model are not sufficient. In MED4 information or data from a knowledge base should be referenced by the process steps [JMML05]. Therefore a new perspective, the *Knowledge Perspective,* is introduced. The main purpose of a knowledge perspective is the integrated modeling of knowledge links in a process model.

3.3 Analyzing Process Models

Process models are not only suitable for documentation purposes, but can also be used to analyze the process itself. In this section we will shortly describe how the language extensions introduced in Section 3.2 foster the systematic analysis.

All processes that have been designed with the iPM modeling tool are stored in a meta-data repository which is based on a relational database schema. This repository schema can be queried arbitrarily. In Fig. 7 one sample report that implements the schedule introduced in ORG1 is presented. It selects all process steps which belong to a certain medical pathway from the repository and displays their dates and examination rooms. This report is common in clinics and can be used by the medical staff to inform the patient about his daily routine.

In addition to the report presented here, many others are implemented according to the scenarios in Section 2. Besides the creation of reports it is also possible to use processes for the generation of an execution environment. We will not discuss this topic here any further and refer to [MuJa07] instead.

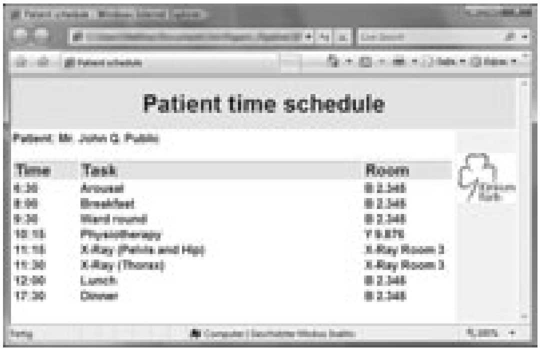

Fig. 7. Patient schedule

4 Conclusion

The main purpose of this paper was to introduce a comprehensive modeling language for Clinical Processes. Its necessity was demonstrated in several use cases which can be attributed to either the medical, organizational or economical dimension. Each of these dimensions highlights a different facet of the daily work in a clinic. Therefore it is essential that these dimensions are presented in a modeling language for Clinical Processes. Also the implementation of such a clinical modeling language was described. Besides its basic and general purpose, modeling elements of this language can be extended with new attributes, constructs or perspectives. Therefore it can be adapted to the requirements of a clinic and easily integrate new modeling requirements. Our experience shows that adaptability is one of the key properties of a process modeling language, as process modeling is always an ongoing task: not only new process models have to be recorded or updated; it will always be the case that newly detected requirements necessitate the extension of a process modeling language. Therefore, we regard extensibility of such a process modeling language as one of their most essential features.

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